# Bubble Growth and Rise in Gassy Sediments

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## LONG-TERM GOALS

Our long-term goal is a quantitative, mechanistic and predictive understanding of the dynamics of bubbles and bubble populations in marine sediments. We believe that this information can be used to improve and test acoustic backscatter models for sediments and to better understand the ebullitive flux of methane, an important "greenhouse gas", to the atmosphere.

## OBJECTIVES

The overall objective of our work is to understand bubble growth and rise in natural marine sediments. In the first phase of our study we demonstrated that bubbles often grow and rise in sediments by the mechanism of fracture. In the second phase we are working to further validate our results from phase one, expand our experimental observations and models of bubble growth to include a broader range of natural marine sediments, and parameterize bubble rise and particularly rise by the mechanism of fracture in natural and surrogate sediment materials.

## APPROACH

We have a strategy of coordinated laboratory, field and modeling research to achieve our objectives. The laboratory work aims to: 1) validate our fracture model for bubble growth, 2) determine how bubbles rise in sediments through studies of surrogate and natural sediment samples and 3) develop a probe for laboratory and field use to measure the sediment properties that control bubble growth and rise, e.g., for fracture these properties are Young's modulus, E, and the critical stress intensity factor, $K_{1c}$. In field work we will measure the mechanical properties that control bubble growth and rise, e.g., E and $K_{1c}$, in a broad range of sediment types and will relate these measurement results to other sediment properties, e.g., organic content, salinity and porosity. In modeling we will focus on understanding and describing laboratory and field results, and will seek to identify the minimum subset of variables that will predict rates of bubble growth and rise in natural marine sediments.

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## WORK COMPLETED

In this fiscal year we have: 1) designed and fabricated a field fracture probe and an instrument for measuring Young's modulus; 2) used these instruments to build a database of $K_{1c}$ and Young's modulus measurements from a range of sediment types at three near shore sites on the coast of Nova Scotia; 3) collected sediment samples corresponding to each $K_{1c}$ profile which are being processed for organic matter content, salinity and porosity; 4) made measurements of bubble rise speed in gelatin (a surrogate sediment material) at a range of temperatures and concentrations, and have begun modeling these results using $K_{1c}$ profiles measured with our fracture probe.

## RESULTS

In the first phase of our study we measured pressure during injection of small amounts of air into natural and surrogate sediment materials. X-ray and visual results showed that the bubbles that formed in most of our samples grew in the shape of disks with principle axes oriented vertically. We subsequently demonstrated that the process is consistent with the mechanism of bubble growth by fracture. We then showed that our results could be described by "linear elastic fracture mechanics", or LEFM. In this, the simplest description of fracture, the geotechnical properties that fully determine fracture strength and the size and shape of resulting cracks are the 'critical stress intensity factor', $K_{1c}$, and Young's modulus, E. We then determined the magnitudes of $K_{1c}$ and E for samples collected at our study site in Cole Harbor, Nova Scotia and reported these results in the Journal of Marine Geology (2002). As far as we are able to determine, ours are the first published measurements of $K_{1c}$ to be reported for marine sediments.

In this, the second phase of our study of bubble growth and rise in marine sediments, we have developed a sediment lander that is fitted with fracture and temperature probes that provide continuous profiles of $K_{1c}$ and temperature as a function of depth of penetration in the sediments. Probe measurements are logged in real time via cable to shore. Laboratory determinations of $K_{1c}$ by two other methods, i.e., bubble injection and minimum bubble size to initiate rise, show that the fracture probe measurements can be interpreted as $K_{1c}$ by assuming that the fracture produced by the probe propagates as a deep edge crack with the same dimensions as the probe. The fracture probe lander is shown in figure 1 at one of our field sites in Cole Harbor, Nova Scotia. Figure two shows a profile of $K_{1c}$ made with the lander at our field site near Prospect, Nova Scotia.

***Figure 1: Sediment lander deployed at our field site in Cole Harbor, Nova Scotia. The lander is fitted with probes to measure temperature and the critical stress intensity factor, $K_{1c}$***

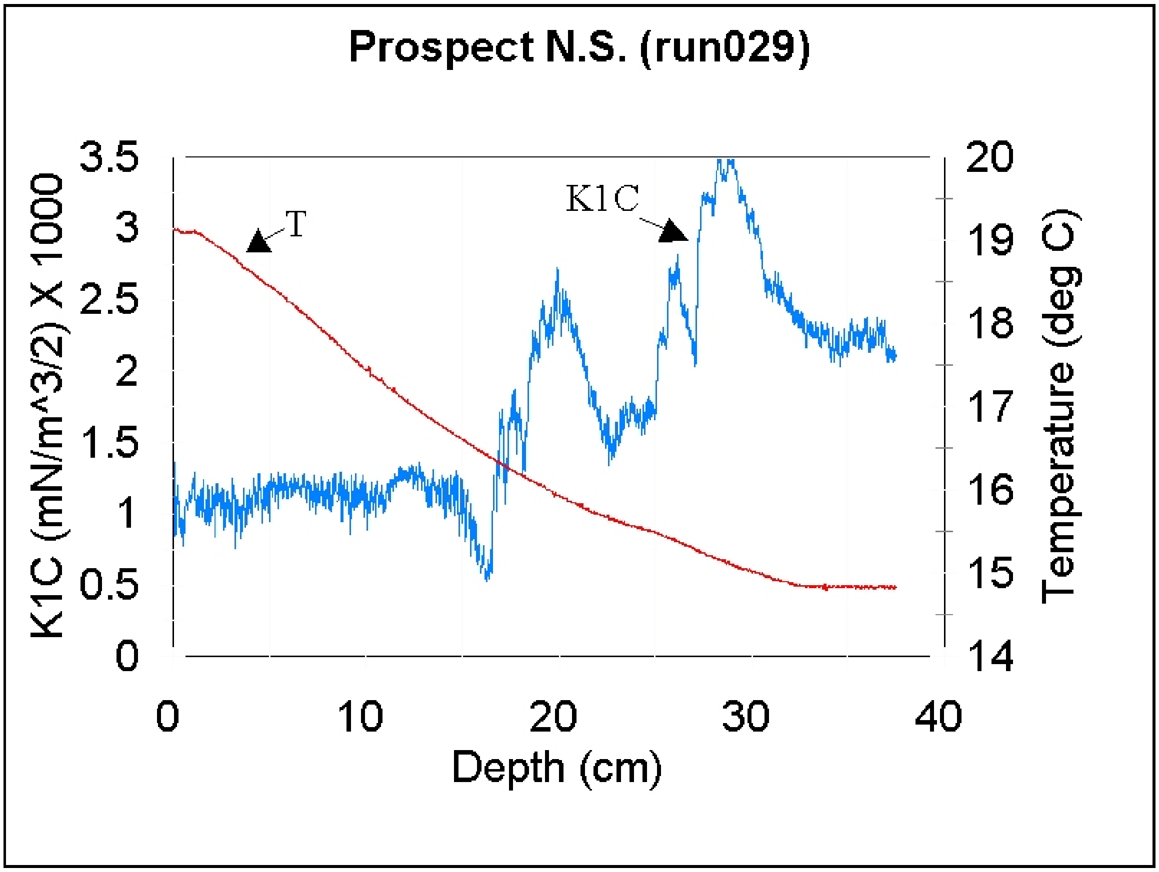


***Figure 2: profiles of critical stress intensity factor, $K_{1c}$ and temperature measured at our field site near Prospect, Nova Scotia.***
***[$K_{1c}$ ranges from near 1 X$10^{-3}$ mega-Newtons meter$^{-3/2}$ over the depth interval of 0 to 15 cm, then rises to a peak of almost 3 X$10^{-3}$ mega-Newtons meter$^{-3/2}$ at 20 cm depth and then rises to another peak of 3.5 X$10^{-3}$ mega-Newtons meter$^{-3/2}$ at 30 cm depth and then finally settles back to about 2.5 X$10^{-3}$ mega-Newtons meter$^{-3/2}$ at 35 cm depth and remains at that level to the maximum depth of 38 cm. Temperature decreases from 19 °C to 15 °C over the same depth interval, i.e., 0 - 38 cm.]***

## IMPACT/APPLICATIONS

Bubbles in sediments can seriously compromise acoustic sensing of naval mines, destabilize structures that rest on the bottom, and transport methane, a potent greenhouse gas, to the atmosphere. Thus, understanding bubble formation and movement in sediments constitutes an important practical and scientific problem. Our findings will provide information that may be used in prediction of: bubble populations and residence times in sediments, mechanical stability of the seabed, rates of methane flux to the atmosphere and acoustic transmission.

## PUBLICATIONS


Gardiner, B.S., B.P. Boudreau and B.D. Johnson. Growth of disk-shaped bubble in the presence of a distributed source of gas; in press in: Applied Math. Modelling.

Gardiner, B.S., B.P. Boudreau and B.D. Johnson. Growth of disk-shaped bubbles in sediments 2003; Geochim. Cosmochim. Acta., 67, 1485-1494.

Johnson, B.D., B.P. Boudreau, B.S. Gardiner and Regine Maass 2002. Mechanical response of sediments to bubble growth; J. Mar. Geol., 187, 347-363.